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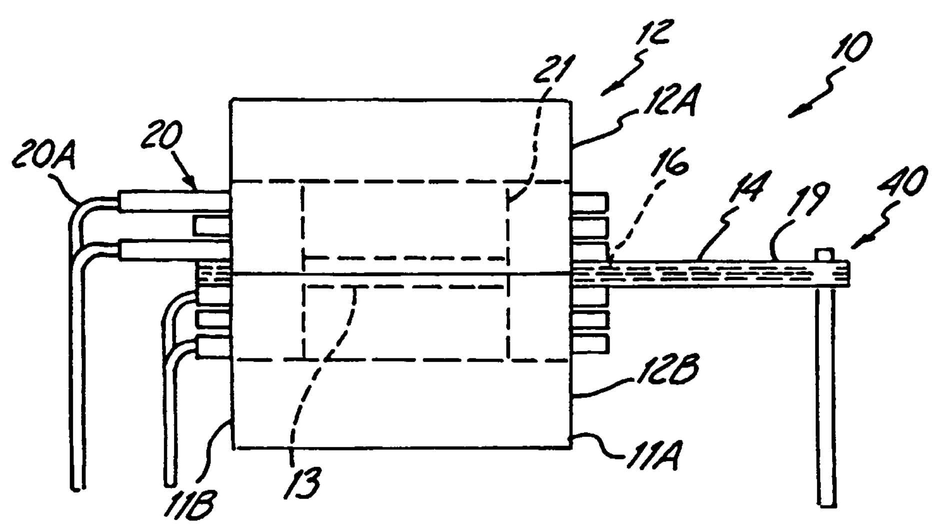
(54) Title: HYBRID TRANSFORMER



(57) Abstract: A transformer (10) includes a magnetic core assembly (12) forming a substantially closed magnetic path. The magnetic core assembly (12) comprises a center leg portion (30) and outer leg portions (32). A primary winding (14) comprising a planar support (16) and a conductive element (40) secured to the planar support (16) is disposed around a first portion (13) of the center leg portion (30). A secondary winding (20) is disposed around a secondary portion (21) of the center leg portion (30). The secondary winding (20) includes a helical coil off a flat electrically conductive ribbon (see figures 7A and 7B) having a width greater than a thickness.

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HYBRID TRANSFORMER

BACKGROUND OF THE INVENTION

The present invention relates to power transformers. More particularly, the present invention relates to a high frequency, high current, low-profile, isolated power transformer having improved magnetic coupling and reduced manufacturing costs.

There is an ever-increasing need for reliable, stable and low cost power supplies to be used in today's technology driven society. For example, microprocessors are being used in an ever-widening variety of applications. The microprocessors can require high power current, yet given the application, severe constraints can be placed on the overall size of the electronic device. Needless to say, significant burdens are placed upon designers to fit all the required components of the device within the volume constraints imposed. Accordingly, there is a need to reduce the size of the power supply, yet in many applications more power is desired.

There has also been a change in the architecture of some power supplies. Specifically, it has been found that the use of distributed power supplies, i.e., placing a plurality of power converters close to the individual loads in electronic systems instead of using one centralized power supply, improves the performance of these electronic systems. However, placing each of the power converters close to the corresponding loads introduces yet further challenges. For instance, some electronic systems include circuit cards installable in slots. The spacing between the slots limits the size of the components placed on the circuit cards, and if the cards are also to include power converters, components thereof also are limited in size.

Many have recognized significant problems in

reducing the size of the power supply such as in a distributed environment. In particular, there is a need to reduce the size of the power transformer used in the power converter, because it is typically one of the largest components making up the power converter. However, reducing the size of the power transformer is not a simple task. Commonly, the power transformer is used in a high frequency switching circuit. The high frequency current causes conduction losses in the transformer, which in turn, generates thermal energy that must be dissipated. As the size of a transformer is reduced, the ease of dissipating heat energy is diminished. Other factors that also should be considered include maintaining the required electrical isolation between the primary and secondary windings as the transformer is reduced as well as maintaining a sufficient electromagnetic coupling between the primary and secondary windings in order to maintain efficiency.

Although there have been some new low-profile transformer designs, there is a continuing need for an efficient power transformer having a low-profile that is easy to manufacture.

SUMMARY OF THE INVENTION

A transformer includes a magnetic core assembly forming substantially closed magnetic paths. The magnetic core assembly comprises a center leg portion and outer leg portions. A primary winding, comprising a planar support and a conductive element secured to the planar support, is disposed around a first portion of the center leg portion. A secondary winding is disposed around a second portion of the center leg portion. The secondary winding includes a helical coil of a flat electrically conductive ribbon

having a width greater than a thickness.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG 1. is a top plan view of an exemplary transformer of the present invention.

FIG. 2 is a side elevation view of the transformer of FIG. 1.

FIG. 3A is a top plan view of an upper insulating board.

FIG. 3B is a top plan view of a first conducting layer.

FIG. 3C is a top plan view of a second conducting layer.

FIG. 3D is a top plan view of a lower insulating board.

FIG. 4 is a top plan view of a multi-turn conducting layer.

FIG. 5 is a schematic diagram of the transformer of FIG. 1.

FIG. 6A is a side elevational view of an upper core member.

FIG. 6B is a top plan view of the upper core member.

FIG. 7A is a side elevational view of a first secondary winding.

FIG. 7B is a top plan view of the first secondary winding.

FIG. 8A is a side elevational view of a primary winding assembly.

FIG. 8B is a top plan view of the primary winding assembly.

FIG. 9A is a side elevational view of a second secondary winding.

FIG. 9B is a top plan view of the second secondary winding.

FIG. 10A is a side elevational view of an lower core member.

FIG. 10B is a top plan view of the lower core member.

DETAILED DESCRIPTION OF THE ILLUSTRATIVE EMBODIMENTS

FIGS. 1 and 2 are a first exemplary embodiment of a transformer 10 of the present invention. Generally, transformer 10 includes a magnetic core 12 forming substantially closed magnetic paths. Although illustrated wherein the magnetic core 12 comprises a solid magnetic material, those skilled in the art can appreciate that small air gaps or other insulating materials may be present in the magnetic paths, if desired. A primary winding 14 is disposed around a first portion 13 of the magnetic core 12. A planar support 16 having a major surface supports and insulates the primary winding 14. Commonly, an insulating member 19 is provided to further insulate the primary winding 14. A secondary winding 20 is disposed around a second portion 21 of the magnetic core 12. The secondary winding 20 comprises a helical coil of a flat electrically conductive ribbon (see also FIG. 7A and 7B) having a width greater than the thickness. Helical ribbon windings are well known and are described in U.S. Patents 4,814,735 and 4,813,126, which are hereby incorporated by reference in their entirety. Generally, the secondary winding 20 is formed of a conductor having a rectangular cross section and coated or otherwise enclosed by an insulating envelope. The conductor of the secondary winding 20 is formed of a metal having good electrical conducting properties, such as copper or aluminum, and is reformed in the circular helical configuration,

best shown in FIG. 7A. The flat helical coil ribbon conductor of the secondary winding 20 is particularly suitable for higher currents and can be formed in a compact structure.

In the illustrated embodiment of the magnetic core 12 is an "E" core having a circular center leg 30 and outer legs 32 (FIGS. 6A, 6B, 10A and 10B). Both the primary winding 14 and the secondary winding 20 are disposed about the center leg 30 and within windows 36 formed between the center leg 30 and the outer legs 32. For example, such cores include PQ20. This embodiment realizes a compact construction, low-profile, safety-insulated, high power density (watts/cubic inch), and easily built transformer. Although illustrated wherein the magnetic core 12 comprises substantially similar core halves 12A and 12B, those skilled in the art will recognize that other non-symmetric core constructions can also be used.

The primary winding 14 can be formed using any one or a combination of known techniques. For instance, flat, discreet wire windings can be supported on planar insulators and sandwiched therebetween, if necessary, to provide adequate insulation. Likewise, "stamped" copper or metal windings can be used. In one particularly useful construction, the primary winding 14 is formed using conventional printed circuit board techniques wherein electrical conductors are disposed and held in place on an insulating board, for example, fiberglass board.

FIGS. 3A-3D illustrate layers of a multi-layer printed circuit board primary winding assembly 40. The multi-layer printed circuit board assembly 40 includes at least one conductive loop 42 being formed

on a circuit board layer substantially about the center leg 32. In the illustrated embodiment, the multi-layer printed circuit board assembly 40 includes two circuit board layers 40A and 40B, each layer having a conductive loop 42 disposed thereon. The loops 42 are connected together, typically in series, through vias or pins 44 as is known in the art. The printed circuit board assembly 40 can have any number of inner circuit board layers, wherein each layer includes a conductive loop 42. For example, many transformers constructed in this manner would have typically 6 to 12 inner circuit board layers, each circuit board layer having a conductive loop 42. The amount of voltage applied to the primary winding and the position of the primary winding 14 relative to the magnetic core 12 and to any secondary winding 20 influence the amount of insulating material needed to electrically insulate the circuit board assembly 40. Typically, a top insulating layer 40C will be used to insulate the upper most circuit board layer 40A. In the illustrated embodiment, an additional insulating layer 40D is provided and secured to the layer 40B.

In the illustrated embodiment, each of the layers 40A and 40B comprise a first circular portion 47 and a second, extending portion 49. The circular portion 47 includes a circular aperture through which the center leg 32 extends. Each of the conductive loops 42 is also generally circular so as to reduce losses due to high-frequency conduction of currents conducted therein. Inner walls of the outer legs 32 of the magnetic core 12 conform generally to the circular portion 49 in order to realize a compact structure and maximize magnetic core material forming the closed magnetic paths 13.

Referring back to FIG. 2, terminals 14A of the primary winding 14 are disposed on a first side 11A of the magnetic core 12, while terminals 20A of the secondary winding 20 are disposed on a second side 11B that is opposite to the first side 11. In this manner, required electrical isolation between terminals 14A of the primary winding 14 and terminals 20A of a secondary winding 20 is maintained. In the illustrated embodiment, the terminals 14A of the primary winding 14 are disposed further from the magnetic core 12 than the terminals 20A of the secondary winding 20. The extending portion 49 of at least one of the layers 40A and 40B conveniently allows location of the terminals 14A of the primary winding 14 further away from the magnetic core 12 than the terminals 20A of the secondary winding 20.

At this point it should be noted that the present invention is not limited to a single conductive loop 42 formed on each inner layer of the printed circuit board assembly 40. Rather, in some applications, it may be desirable to form a plurality of conductive loops on each inner layer. FIG. 4 is a top plan view showing the two conductive loops column 42A and 42B formed on one side of the board with a via 44 transferring the conductive member to the other side of the board to form another lead as illustrated with dashed lines. Preferably, an insulating member 46 is present on the top and bottom portions of the multi-layer printed circuit board assembly 40 so as to provide adequate insulation.

In the illustrated embodiment, the transformer 10 includes a second secondary winding 50. The secondary windings 20 and 50 can be connected together to form a single secondary winding, or

alternatively, can remain isolated from each other (as illustrated schematically in FIG. 5). However, it is important to note that in the illustrated embodiment, the primary winding 14 is disposed between the secondary windings 20 and 50 so as to increase magnetic coupling. As appreciated by those skilled in the art, the primary winding could also be split into subsections with the subsections interposed between the secondary windings. As stated above, the primary winding 14 can be formed using discreet winding and insulator elements; however, a multi-layer printed circuit board assembly 40 can be used for each subsection to provide reduced manufacturing costs.

The transformer 10 is well suited for in both AC-DC and DC-DC power converters. The primary winding 14 formed on an insulating planar support such as a printed circuit board and further insulated with other insulating layers as needed provides the necessary isolation of the higher voltages applied thereto. In contrast, the secondary winding 20 formed of the helix ribbon conductor is able to conduct substantially more current than the primary winding at lower voltages. It is believed that the magnetic fields produced by large secondary currents are themselves helical in nature and induce currents that follow helical patterns themselves. In addition, electron flow which is induced in the secondary winding 20 can flow with lower loss from layer to layer in a helical winding because feed through loss is avoided because the three dimensional structure of the helix allows for the natural flow to the next winding level smoothly and efficiently. Typically, a via can handle only a few amperes each. But these limitations are avoided by using the vias only for the

lower current primary winding 14.

It has been discovered through high frequency loss analysis that the construction of the present invention promotes low loss. In particular, since the transformer 10 is very compact due to planar orientation of both the primary winding 14 and the secondary winding 20 (when the helical turns are pressed together), leakage inductance of the transformer 10 is minimized, which in turn, increases the efficiency of the transformer 10. This low loss effect becomes even more important when the application requires large output currents to flow in the secondary winding 20. In a preferred embodiment, the sustained secondary current flow is greater than 25 amps with the present construction when operated at high frequencies (greater than 250 kilohertz). In a further embodiment, the sustained current flow is greater than 50 amps when operated at high frequencies. In yet a further embodiment, the sustained current flow is greater than 100 amps when operated at high frequencies. Each of the foregoing embodiments are passively cooled (i.e., non-forced cooling).

Likewise, previously unobtainable power densities have been realized in a low-profile power transformer. For instance, one particularly useful application of the transformer 10 of the present invention includes applying 120 to 250 Volts AC to the primary winding 14, while maintaining required electrical isolation between the primary winding 14 and the secondary winding 20 (e.g. 3500 Volts). In such an application and without forced cooling (fans, etc.), greater than 500 watts/inch^3 can be obtained. In a further embodiment for this application under the

foregoing criteria, greater than 750 watts/inch^3 can be obtained. In yet a further embodiment, greater than 1000 watts/inch^3 can be obtained under the same conditions. As appreciated by those skilled in the art, smaller power transformers can now be used, which saves critical space on the circuit board or in the electrical device, while efficiently obtaining more secondary current.

Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention.

WHAT IS CLAIMED IS:

1. A transformer comprising:

a magnetic core assembly forming closed magnetic paths, the magnetic core assembly having a center leg portion and outer leg portions;

a primary winding comprising a planar support and a conductive element secured to the planar support and disposed around a first portion of the center leg portion; and

a secondary winding disposed around a second portion of the center leg portion, the secondary winding comprising a helical coil of a flat electrically conductive ribbon having a width greater than a thickness.

2. The transformer of claim 1 wherein the primary winding and planar support comprise a printed circuit board.

3. The transformer of claim 1 wherein one of the primary winding and the secondary winding includes subsections connected in series, and wherein the subsections are spaced-apart on the core and the other winding is interposed between the spaced-apart subsections.

4. The transformer of claim 1 and further comprising a second secondary winding disposed around a third portion of the center leg portion.

5. The transformer of claim 1 wherein the primary winding is located between the secondary windings on the center leg portion of the magnetic core.

6. The transformer of claim 2 wherein the printed circuit board comprises a multi-layer printed circuit board having a conductive loop disposed on each of a plurality of the layers and wherein each conductive loop is disposed substantially about the corresponding portion of the magnetic core.

7. The transformer of claim 6 wherein each of the plurality of layers includes a plurality of spirally wound conductive loops.

8. The transformer of claim 1 wherein terminals of the primary winding are disposed on a first side of the magnetic core and terminals of the secondary winding are disposed on a second side of the magnetic core that is opposed to the first side.

9. The transformer of claim 8 wherein the terminals of the primary winding extend further from the magnetic core than the terminals of the secondary winding.

10. The transformer of claim 1 wherein the center leg portion is circular and the planar support includes a circular aperture of size to receive the center leg, and wherein the conductor of the primary winding forms a circular pattern about the circular aperture.

11. The transformer of claim 10 wherein the planar support comprises a first circular portion having the circular aperture and an extending second portion to locate terminals of the primary winding away from the secondary winding.

12. The transformer of claim 11 wherein the outer leg portions of the magnetic core have inner walls conforming to the first circular portion.

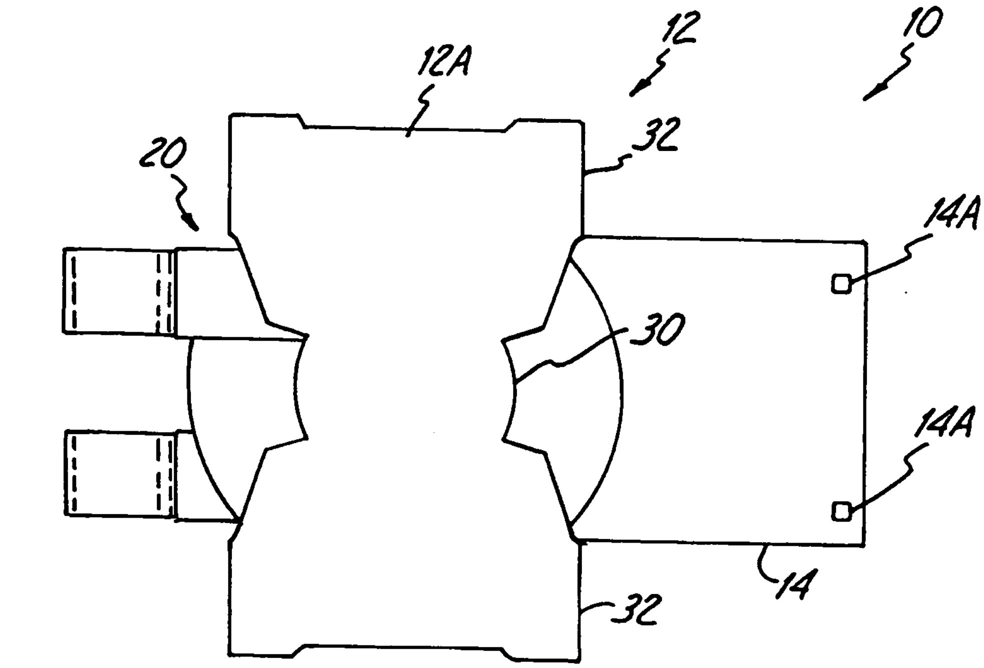
12A
12
10
20
32
14A
30
14A
14
32

Fig.1

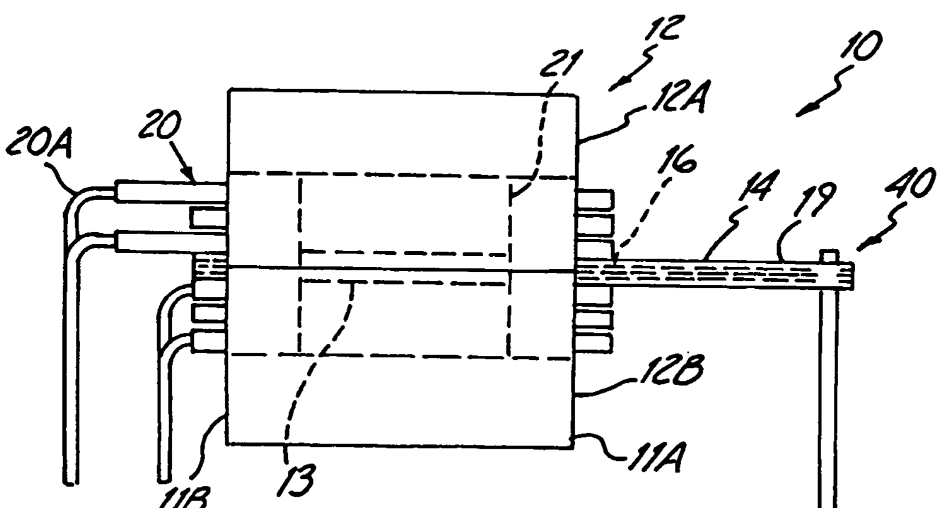
21
12
10
12A
20A
20
16
14
19
40
12B
11A
11B
13

Fig.2

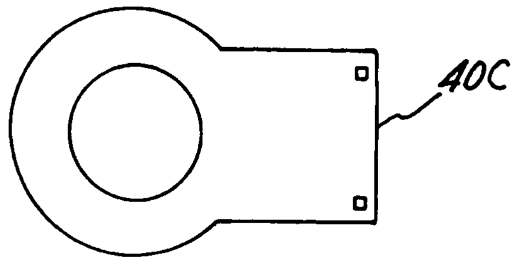

Fig.3A

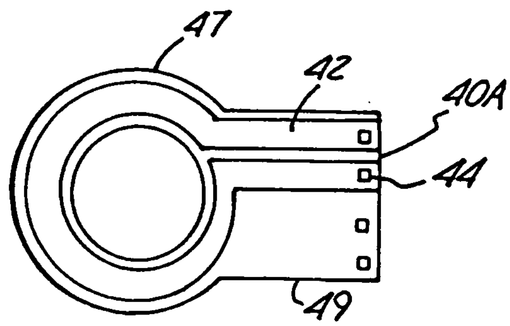

Fig.3B

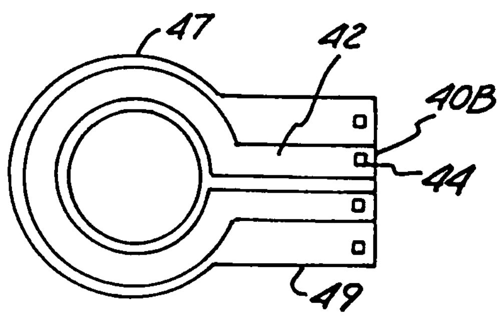

Fig.3C

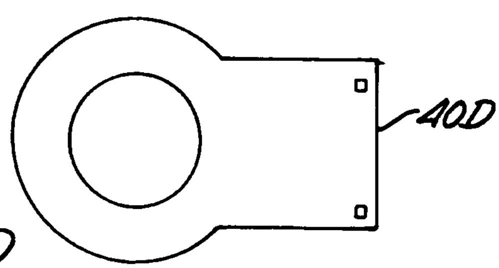

Fig.3D

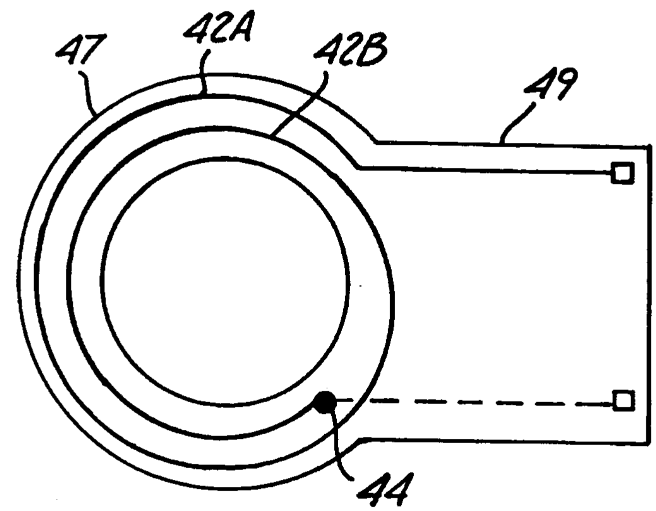

Fig.4

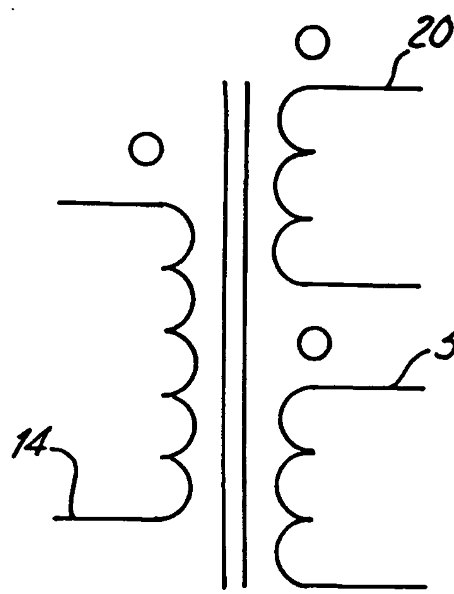

Fig.5

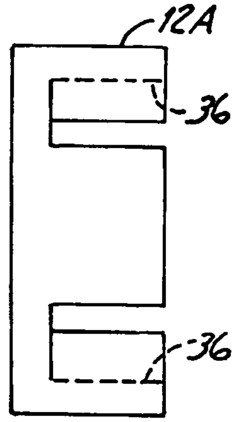

Fig.6A

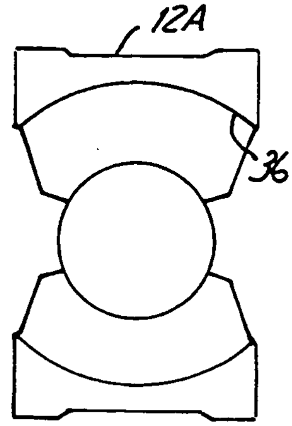

Fig.6B

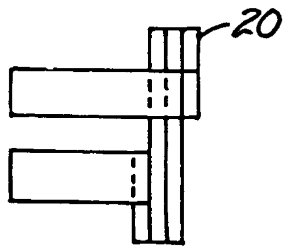

Fig.7A

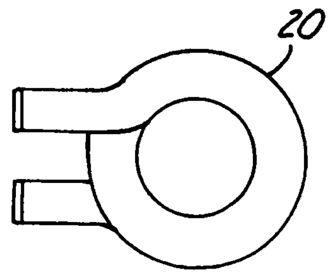

Fig.7B

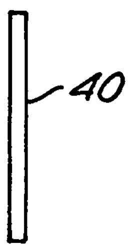

Fig.8A

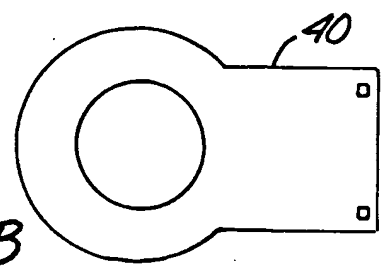

Fig.8B

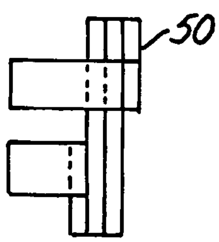

Fig.9A

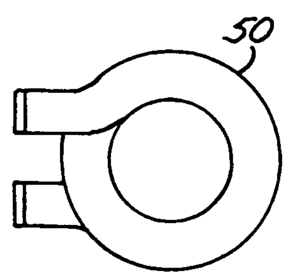

Fig.9B

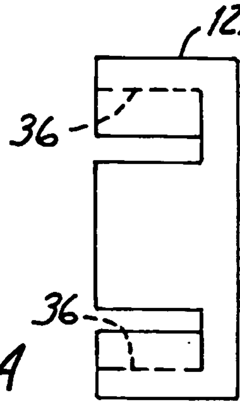

Fig.10A

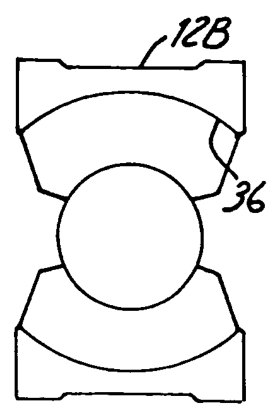

Fig.10B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/23813

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7) : H01F 27/06, 27/29, 27/30
US CL : 336/65, 83, 192, 200, 223, 232
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 336/65, 83, 192, 200, 223, 232

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
NONE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y,E	US 6,114,932 A (WESTER et al.) 05 September 2000 (05.09.2000), see entire document.	1-12
Y,P	US 6,046,662 A (SCHROTER et al.) 04 April 2000 (04.04.2000), see entire document.	1-12
Y	US 5,017,902 A (YERMAN et al.) 21 May 1991 (21.05.1991), see entire document.	1-12

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27 September 2000 (27.09.2000)	17 OCT 2000

Name and mailing address of the ISA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703)305-3230	Michael Gellner Telephone No. (703)308-0956

Form PCT/ISA/210 (second sheet) (July 1998)